CHAPTER 4
PLANNING AND PROCEDURES

4-1. Considerations. The need for grouting should be determined early in the planning stage of a project and should be governed by the requirements for the particular structure and geologic setting. Grouting to reduce seepage that might have an adverse effect on performance of a structure is the most common design purpose for grouting. Grouting also provides thorough exploration of possible adverse conditions. If foundation seepage is not detrimental to the structure, a deep grout curtain may not be necessary. Economics may dictate grouting to reduce water losses in cases where water is valuable, such as in an upper reservoir of a pumped storage project.

a. Geologic Considerations. Plans for a grouting program should be based on the knowledge obtained during exploratory investigations of the geologic conditions. The design of grouting programs should never be based on a predetermined formula, but should be selected to accomplish the design purpose of the grouting in the geologic setting at hand. Geologic considerations are required from the initial planning stage through the completion and evaluation stages of the grouting program.

b. Program Objectives. The planning of grouting operations and techniques is not only influenced by the subsurface conditions encountered, but also by the purpose and objectives of the grouting program. Is the grouting intended to be a permanent treatment, or is it a temporary construction expedient? Is the tightest cutoff obtainable needed, or is something less than that acceptable? Should the maximum amount of grout possible be injected into the rock regardless of spread, or should an effort be made to restrict the spread to reasonable limits, or should it be restricted to very narrow limits? The answers to these questions and the effects of the often overriding factors of time and cost form the basis for planning drilling and grouting operations. The treatment of a reservoir to permanently store a liquid pollutant is an example of one extreme. Sufficient time and money must be allocated and every effort and decision designed to provide the tightest seal possible, otherwise the project cannot be successful. At the other extreme, a grouting program may be conceived to reduce, but not necessarily to stop, seepage into an excavation during construction as a measure to save on dewatering costs. Time will be a factor if grouting delays other work. Cost is a factor, since the saving on dewatering costs must be a ceiling for grouting costs. Permanence of treatment is not vital in this case, and grouting techniques are directed toward constructing the most effective cutoff possible for a specified expenditure of time and money. The objectives of most grouting operations fall between the examples cited above. The objectives for all grouting should be clearly defined so that the designer, geologist, project engineer, and inspector will understand them and can then contribute to their realization.

4-2. Planning Considerations.

a. After the need for and purpose of grouting has been determined, the planning of a grouting program can begin. Planning should consist of:

(1) Making a study of exploratory investigations and using the information to determine the extent, method, and parameters for the safe and efficient injection of grout into the foundation and that will provide the optimal hole orientations, depth, and spacing.

(2) Determining at what project construction stage the grouting should be done.

(3) Preparing suitable plans and specifications that will represent site conditions and work to be performed.

(4) Estimating drilling quantities and amount of grout materials required.

b. Unforeseen geological conditions may necessitate modification of the grouting program after grouting operations are under way. Therefore, flexibility should be provided as an integral part of planning and should be preserved through the completion of the grouting.

c. Grouting is usually on the critical path of construction, and, with particular weather restraints, there is a tendency to modify or curtail grouting as a construction expedient. Once the determination is made that grouting is a required part of design, it cannot become secondary to any time or scheduling restrictions.

4-3. Quality Management. It is extremely difficult to determine the quality of the end product resulting from a grouting operation. As a consequence, the portions of a construction contract dealing with grouting almost invariably specify a very detailed construction procedure. The specified detailed construction procedure and the difficulty in determining the quality of the post-grouting end product combine to make the grouting quality management program extremely important.

a. Quality of Personnel. Guidance for Corps personnel staffing on Civil Works Construction Projects is contained in ER 415-2-100. Staffing for grouting work shall be with qualified personnel, preferably with key personnel having prior grouting experience. The staff shall include an engineering geologist or geotechnical engineer and one or more technicians qualified to perform the day-to-day supervision of grouting activities. The geologist or engineer shall be experienced in grouting and foundation design. Depending on the complexity of the project other technical specialists may be required. These specialists shall either be assigned directly to the project or be available for prolonged and frequent temporary assignments from other organizations. On large projects, assignments in the early stages of grouting may be arranged so that inexperienced personnel can observe the action and decisions made by an experienced staff. Thus, a competent team can be trained that will operate at maximum efficiency at a later time when the work is in full swing. Some grouting operations, however, may not involve a large organization, and the grouting technician will not have anyone with experience in the peculiarities of this work to whom he can turn quickly for advice and counsel. Only experienced construction personnel should be given such assignments.

b. Grouting Records. Under most contract requirements, the contractor will keep daily records of all items for measurement and payment. These items should be reconciled on a daily basis and agreement reached between the contractor and Government on all measured quantities. Disputes over payment items should be reconciled as soon as possible between responsible representatives of the contractor and the Government. The contracting officer will keep records of all grouting operations, including but not limited to a log of the grout holes, results of washing and pressure testing operations, time of each change of grouting operation, pressure, rate of pumping, amount of cement for each change in water-cement ratio, and other data as deemed necessary. These records are a valuable tool for the evaluation of each step of the grouting program. To facilitate control of the grouting program and provide a graphic picture of the results for review, an up-to-date visual plot of the grouting operations should be maintained. A further detailed discussion of grouting records and reports is contained in Chapter 15.

4-4. Grout Hole Drilling.

a. Location. The location for the grout holes is determined by the type of structure to be grouted, geologic conditions, and purpose of the grouting.

b. Hole Size. The diameter of grout hole selected will be based upon the type and condition of the rock to be grouted and the depth and inclination of the hole. The grout hole required should normally be specified as the minimum acceptable diameter. The contractor may elect to drill a larger diameter hole. Minimum hole sizes normally specified range from 38 to 76 millimeters (1.5-3 inches). Except where percussion drilling is used, the smaller diameter holes may be preferred because of their lower cost.

c. Selection of Minimum Hole Size. Hard rock with widely spaced, relatively clean fractures may be successfully grouted through EW (38 millimeters) holes. Larger diameter holes are required for successful drilling and grouting in rock of poorer quality. Conditions to be considered are rock formations that (1) tend to cave in, (2) contain fractures filled with unconsolidated material, or (3) contain open joints and fractures which may be intruded by drill cuttings. The larger diameter holes will allow the insertion of a wash pipe or tremie pipe in the hole with sufficient space between the pipe and the wall of the hole for removal of cuttings or grout and for washing or backfilling. Larger diameter holes may also be required to produce a straighter hole. Drift due to smaller diameter and more flexible drill rods may be excessive. Other factors affecting minimum hole size include hole depth, anticipated grout mixture, and method of grouting.

d. Spacing. The spacing, as well as the pattern, of grout holes should be based on geologic conditions, the results expected to be obtained, and the purpose for which the grouting is being done. The spacing will be influenced by the characteristics of the foundation and, in the case of curtain grouting, by the hydrostatic head to which it will be subjected. Primary hole spacings should be sufficiently wide so that connections between grout holes do not normally occur. In practice, primary hole spacing commonly varies from 10 to 40 feet. Final spacing between 2-1/2 and 10 feet is common for curtain grout holes. Aside from primary hole spacing and the maximum allowable spacing, however, grout hole spacing cannot be predetermined satisfactorily. The final spacing should be determined during the grouting operations on the basis of the results being obtained from these operations. Holes in curtain grouting, for example, may still take considerable quantities of grout after hole spacing has been reduced to an anticipated minimum interval, and the spacing should be reduced further until the section or area is considered to be grouted satisfactorily. Curtain grout holes on some projects have been spaced as close as 1 foot on center.

e. Depth. The depths to which grout holes are drilled should be governed by conditions in the foundation rock, and for curtain grouting, by the hydrostatic head to which the foundation rock will be subjected. Depths for a grout curtain should be sufficient to minimize seepage and assist in the reduction of uplift and the need for extensive drainage facilities. Where conditions permit, grout holes should bottom in sound, relatively impervious rock. Depths should never be based simply on precedent.

f. Direction. Grout holes for curtain grouting of concrete dams are commonly inclined in an upstream direction, and drilling and grouting is done from a gallery. Inclining the holes allows them to intersect vertical or steeply dipping fractures and joints that would not be intersected otherwise, and holes inclined in an upstream direction provide an adequate separation of the grout and drainage curtains. The direction in which to drill any grout hole should be based on the nature of the imperfections to be grouted, the purpose of the grouting, and the environment under which the grouting is done. Grout holes should be drilled in such a direction and angle as to intersect as many of the imperfections in the rock as possible for the prevailing conditions. Angle or horizontal grout holes should be incorporated in abutments where needed.

g. Types of Drilling. Drilling experience gained during foundation investigations should be considered in the selection of the type or types of drilling to be used in the grouting program. There are different types of drilling which may be selected for grout hole drilling. Each has advantages and disadvantages.

(1) Rotary drilling. Perhaps the most common type of drilling used in grouting is rotary drilling. Clear water is normally used as the medium for removal of drill cuttings. Diamond bits are usually used to advance the hole. In some cases the bits may be coring bits and in other cases they may be plug bits. In soft rock drilling, drag bits may be used. In those situations where it is especially important to prevent drill cuttings from intruding rock fractures, reverse circulation rotary drilling may be used. This technique is more time consuming and expensive than conventional rotary drilling and should only be specified in those cases where it is required for satisfactory grout injection. An advantage of the rotary drilling method is that it permits ready identification of intervals in the foundation where drilling fluid is lost, thus allowing the drilling to be stopped and the interval grouted before the fracture or fractures become clogged. Another advantage is that the hole can be washed clean after drilling without removal of the drill from the hole. Disadvantages of rotary drilling are that it may be more costly than percussion drilling, and drill cuttings tend to intrude into fractures by the pressure of the drilling fluid.

(2) Percussion drilling. A second type of drilling is percussion drilling. There are several variations of this technique. One method is to use blast-hole type drills with air and/or water as the medium for removing cuttings. A second method is to use a down-the-hole hammer with air as the medium of cutting removal. Both types of drills have been used successfully for grout hole drilling. In cases where it is necessary to drill through a zone or stratum which contains clay or silt that tends to ball up in the hole and block the passage of the air, small quantities of water may be injected into the air stream with a high pressure, low capacity pump. This often greatly improves performance of the drill through these intervals. In some cases it may also be useful to introduce a foaming agent with the water to facilitate removal of clay cuttings. The advantages of this type of drilling are that it is normally less expensive than rotary drilling, hole advance is faster, and there is less tendency to intrude rock fractures to significant depths with drill cuttings in those cases where air rather than water is used as the medium of cutting removal. A disadvantage is the tendency to smear the wall of the hole with cuttings in soft rock types. After the hole is completed it should be thoroughly washed to remove any smeared cuttings. In some cases, fractures in soft rock are filled with cuttings which cannot be removed by washing. Another disadvantage is that circulation losses are usually not apparent where air alone is used, thus eliminating one of the main criteria on which a decision is made to stop and stage grout the hole after encountering a feature which needs grouting. Another disadvantage is the possibility of subjecting the hole to the full pressure of the compressed air should a blockage occur above the bit. These pressures may be capable of lifting or jacking the foundation due to intrusion of air along low angle fractures in the rock. This concern is magnified if the grout holes are being drilled through a

completed embankment. Blockages in the hole will subject the embankment to the full air pressure and will probably fracture the embankment fill. The use of air drilling in embankments and their foundations has now been prohibited by the Corps of Engineers (ER 1110-2-1807).

4-5. Types of Treatment.

a. General Considerations. The types of grouting treatment applicable to civil construction fall into one of the following categories: (1) curtain grouting, (2) area grouting (also referred to as consolidation, stabilization, or blanket grouting), (3) tunnel grouting, (4) cavity filling, (5) backfilling boreholes, (6) contact grouting, and (7) specialized applications. Treatment by grouting is an important design feature of many dam and structural foundations. Grouting has also been effective many times as a remedial treatment to correct foundation deficiencies or to repair damage.

b. Curtain Grouting.

(1) Curtain grouting is performed to cut off seepage under dams or other structures, or reduce it to a point that it can be controlled economically by the drainage installations. Control is accomplished by drilling and grouting one or more lines of grout holes in the foundation, usually parallel to the alignment of the dam or normal to the direction of water movement. A barrier to the movement of water in the foundation is constructed by filling the voids or water passageways with grout. In theory, the barrier needs only to be a curtain of moderate width. In practice, however, the barrier obtained will be wider than necessary in some places and levels, and possibly not wide enough at others.

(2) The holes for curtain grouting may be drilled on either a single-line or a multiple-line arrangement. The grouting of a single line of holes will ordinarily provide a satisfactory curtain for concrete dams that are constructed on competent rock. The grout curtain is commonly located as far upstream as possible in these cases. The exact location of the curtain is determined by the type of structure as well as by the foundation conditions peculiar to the sites. The grout curtain for dams constructed on inferior rock may consist of a multiple-line arrangement of grouted holes (Figures 7-1 and 7-2). The holes in adjacent rows in a multiple-line arrangement should be staggered with relation to each other. A triple line curtain should be installed in the following sequence: install either the upstream or downstream line, then the other; and lastly the center line. Distances between lines may vary according to field conditions, but generally will not exceed 5 feet. For embankment dams a multiple line should be considered in the upper zone beneath the impervious core. If solutioned rock is present, or where joints or fissures are fine, closely spaced, and erratic, a multiple-line curtain may need to be constructed to the full depth. A single-line curtain is generally used for rim or upland grouting. However, specifications should be flexible enough to add additional lines of grout holes at any location or depth as determined necessary in the field.

(3) Curtain grout holes may be vertical, inclined, horizontal, or any combination thereof as discussed in paragraph 4-4. Grout curtains under embankment dams are generally located in a cutoff trench close to the embankment impervious core center line. Designs requiring an upstream location must consider the possible need for future grouting and the frequency of high pools blocking access. Locations downstream of the impervious section increase uplift pressures under the core. A good procedure at abutments is to incline the holes with a component into the abutment. Horizontal grout holes are sometimes very effective for grouting high angle fractures of limited vertical extent. The depths to which grout holes are drilled should be governed by the hydrostatic head to which the foundation will be subjected and by the geologic conditions in the foundation such as the depths of impervious rock. Depths for a grout curtain should be such that the seepage path is long enough to offer sufficient resistance to seepage and to prevent the occurrence of high exit gradients near the downstream toe or excessively high uplift pressure under the downstream portion of the dam. Grout holes should bottom in sound, relatively impervious rock where possible. Final depths should never be based on precedent. A rule of thumb often used for preliminary planning of hole depth is two-thirds the hydraulic height of the dam. Foundation rock permeability usually decreases with depth. Grouting done from the foundation surface, such as for embankment dams, should use low or near gravity pressures for the upper zone. Grouting through an embankment is sometimes necessary for remedial or deferred grouting. Special precautions should be taken in these cases to avoid fracturing or eroding the embankment. Grouting through a few feet of fill is sometimes required to protect sensitive materials or for winter grouting to insulate the foundation and the freshly placed grout near the surface. In these cases, a good practice is to remove the fill and perform final foundation preparation after the grouting. Grouting of sensitive foundations is sometimes accomplished before excavation of the final 2 or 3 feet to limit freezing or exposure damage.

(4) Grouting from galleries is normally done after the structure is near completion to take advantage of the surcharge so that higher pressures may be used. Drilling for drains should not be done until after grouting is finished.

c. Area Grouting.

(1) Area grouting usually consists of grouting a shallow zone in a particular area utilizing holes arranged in a pattern or grid. The grouting is done (a) to increase the supporting capacity of the rock or (b) to prevent underflow through weathered or partially disintegrated rock, highly fractured rock, or horizontally stratified rock where curtain grouting would not be sufficiently effective. The grouting operation in the first instance is often called "consolidation grouting." Grouting in the second instance merges into multiple-line curtain grouting. Deeper area grouting is sometimes done to grout specific geologic conditions, such as fault zones, or to consolidate subsurface materials at shafts or deep structures. Area grouting near the surface is usually done with low or gravity pressures; however, where deeper

zones are grouted, higher pressures can be used safely.

(2) Area grouting to increase the load-bearing capacity of foundation rock is sometimes used as a means of solidifying seamy but otherwise good rock and thereby decreasing the amount of rock excavation and the amount of concrete backfill. However, the effectiveness of area grouting is questionable under foundation conditions where the seams in the rock are filled with clay, and the clay must be removed before grout injection for consolidation grouting can be effective. Because of the irregular pattern of the seams and the character of the filling material, it is not possible to know how much of the clay actually is removed, and consequently, how effective the grouting has been. It will probably take less time, and may cost less, to excavate broken and seamy rock rather than to treat it by grouting.

(3) Treatment of stratified or seamy rock may result in wasting a large quantity of grout through joints and seams leading away from the foundation area. This waste can be prevented by grouting a line of holes on the periphery of the area at low pressure. Substantial savings may sometimes result from taking these precautions.

d. Tunnel Grouting.

(1) Grout treatment for tunnels may be for backpacking tunnel liners, consolidation of material surrounding the bore, seepage control, contact grouting, or ring grouting. Preexcavation grouting may be required for consolidation and water control. To accomplish grouting after tunnel excavation, imbedded pipes or formed holes are provided through the liner, if necessary. Pressure grouting for backpacking behind cast-in-place concrete liners should not be done until 7 days after the placement of the liner. However, where precast concrete or steel ring liners are used, grouting should be accomplished as quickly as possible after liner placement. A sanded mixture is normally required for grouting behind tunnel liners. Injection begins at the invert and is moved up as grouting proceeds. The final step is contact grouting with neat cement grout at the crown after the liner grouting has been completed and the grout has aged and shrunk.

(2) Ring curtain grouting is a treatment akin to curtain grouting under a dam in that it forms a grout barrier intended to reduce the possibility of water percolating from the reservoir along the tunnel bore. The stage-grouting method usually will produce the best results.

(3) The necessity for grout rings, the number of rings required, and the depth and the spacing of holes in the rings all depend upon the type and the conditions of the rock through which the tunnel is excavated and the anticipated hydrostatic head that will tend to develop seepage through the rock. The rings commonly are located on the extended line of the grout curtain under the dam. Where the rock is fairly tight, however, grout rings may function

more efficiently if they are only a short distance downstream from the control structure location.

(4) The grout rings are formed by drilling and grouting four or more holes equally spaced around the tunnel bore. Split spacing procedures should be used when there is significant grout take. Where multiple ring treatment is required, holes in the alternate rings should be staggered radially. The rings should be as far as practicable from the transverse joints of the lining, especially if the joints do not contain water or grout stops, because leakage of grout from the joints may be difficult to control.

(5) For consolidation grouting or water control the holes generally should extend into the rock well beyond any fracturing that may have been caused by tunnel driving and should intercept as many natural fractures, solution openings, and similar imperfections as possible.

e. Cavity Filling.

(1) Cavity filling is one of the least standarized types of grouting. The effectiveness of grouting a clay-filled cavity is questionable; however, air- or water-filled cavities or large, open joints can successfully be grouted with cement grout. The extent of a cavity is not known after the penetration of a single grout hole. More exploration or drilling may be necessary before treatment can be determined. A thick, tremied grout, grouting of preplaced aggregate, or other materials requiring specialized mixtures may be required.

(2) When a cavity is encountered in drilling, the hole should be grouted. A sanded mixture is normally required to complete the grouting of the cavity. Intermittent grouting may be necessary.

(3) Intermittent grouting is the process of injecting some amount of grout into the hole and waiting several hours before injecting more grout. Several waiting periods may be necessary. During each injection period the last batch of thick mortar grout injected into the hole should be followed by the injection of water into the hole through the pump system. Grouting should resume, after the waiting period, with neat cement grout before returning to injection of the mortar mix. The amount of grout to be injected during each period is normally a predetermined limit. The maximum amount of grout to be injected into a cavity through a single hole should also be predetermined before considering other procedures.

(4) When refusal is reached, it is assumed that grout has at least filled the portion of the cavity penetrated by the grout hole. Additional grout holes are then drilled and grouted until the desired results are achieved.

(5) If pressures fail to build up or the cavity is obviously too large

to grout in this manner, grouting should continue beyond the cavity. Additional exploration, consultation, evaluation, and design of remedial measures can then take place without delaying the contractor. These measures may call for specialized grouting procedures or materials such as foaming agents, positive cutoff diaphragm or formed concrete wall, additional excavation, or some other solution. Tremie or gravity grouting is a method often successfully used to grout cavities or large voids.

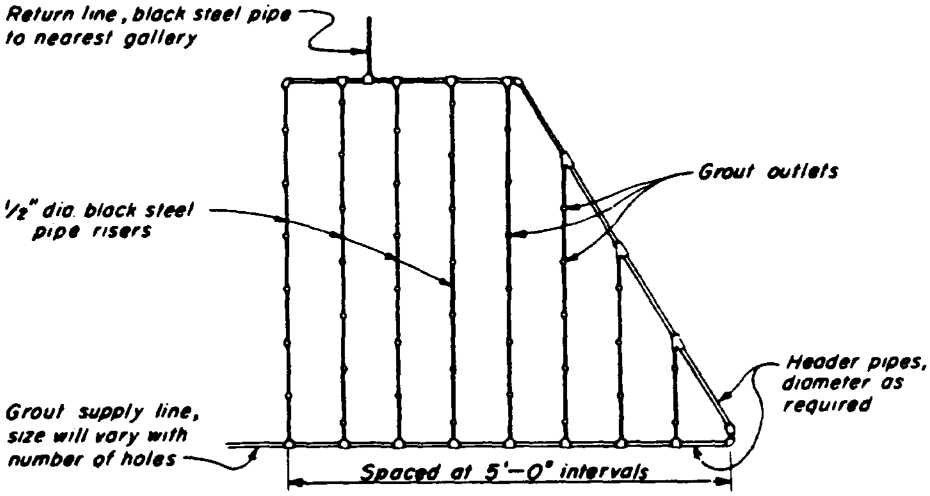
f. Backfilling Boreholes.

(1) Backfilling boreholes and grout holes are an important part of the grouting program. These holes may act like relief wells under the reservoir head, and if not properly grouted, they could contribute to seepage and piping. Holes in the rock foundation should be backfilled with grout that has a water-cement ratio of 1.0 to 0.7 and about 4 percent bentonite. A minimum diameter, 1-inch delivery line with a steel section at the end is extended to the bottom of the hole after the line is completely full of grout. Grout is then pumped until it flows from the hole, and the delivery line is slowly withdrawn while pumping continues. If settlement of grout occurs, the holes are topped off or rebackfilled before fill is placed.

(2) The tremie method is also used to backfill holes in embankments or fill; however, the backfill mix in these applications is designed to be more plastic.

g. Contact Grouting. Contact grouting is the injection of neat cement grout at the contact of a concrete structure with an adjacent surface. Contact grouting fills the void at the contact that results from shrinkage. Contact grouting may be done through either header pipes installed for that purpose during construction, or drill holes. The header pipes or grout holes are thoroughly washed before the grouting operation. Grouting pressures may vary but the highest safe pressure should be used. Contact grouting is a sealing operation intended to bring about a fully bonded contact between any concrete or steel structure and the adjacent rock. Shrinkage of the concrete as it sets or deflection of the loaded structure may produce seepage paths along the contact. Contact grouting is advisable where such conditions are critical. This treatment is used most frequently in the abutment areas of concrete dams and in the crown areas of lined tunnels in rock. The grouting is usually done in both instances after the main structure has been completed. A typical piping arrangement for contact grouting is shown in figure 4-1.

h. Soil Grouting. The methods described in a through g, above, were developed primarily for grouting rock, and may or may not be applicable for grouting soil. Soil grouting is usually conducted to reduce or arrest water movement and/or for increasing the bearing load of the soil, to reduce settlement, and to improve resistance of soil to erosion by water and/or rain. The term soil is used here in the broadest sense, and includes unconsolidated granular materials ranging from clays with increasing coarseness through fine,



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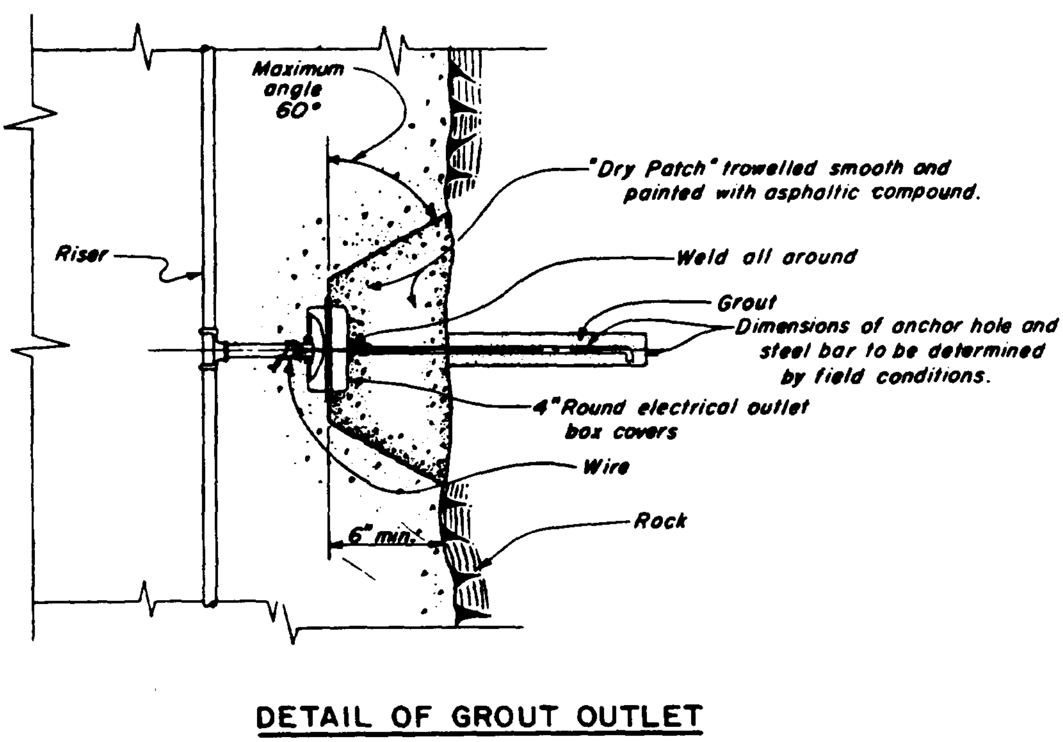

DETAIL OF GROUT OUTLET

Figure 4-1. Detail of contact surface grouting medium, and coarse silts; fine, medium, and coarse sands; and up to and including fine gravels. A method for determining the limits of groutability for the coarser granular soils, i.e., medium sands through fine gravels, is described in paragraph 5-2e. Treatment of fine granular materials, i.e., through coarse silts, is covered in EM 1110-2-3504. Methods of soil grouting are summarized as follows:

(1) Casing. A casing may be drilled, jetted, or pushed to the full depth to be treated and then withdrawn as grout is pumped into the soil. The escape of grout up the contact surface of the casing and the soil may be a problem. This method is used extensively in chemical grouting at shallow depths.

(2) Grout sheath. In this method, a flush-joint grout pipe is grouted in, using a special brittle grout that prevents leakage up the outside of the pipe. The grout pipe is withdrawn a short distance, leaving a brittle grout sleeve below the pipe. Grout is pumped into the soil through cracks produced by the pressure of the grout in the brittle grout sleeve below the end of the grout pipe.

(3) Pierced casing. A patented soil grouting method has been developed in which the casing is grouted in using a special grout. The casing can be pierced at any selected point by firing an explosive-impelled projectile from a device lowered into the casing.

(4) Tubes a manchette. In this method, a perforated pipe is grouted into the hole with a special sleeve grout. The perforations are covered with short sections of a rubber sleeve (manchettes) on the outside of the pipe that act as one-way valves. Perforated sections of the pipe are placed opposite injection locations. A double packer is used to control the treatment location. The pressure on the grout pumped into the hole between the confining packers causes it to push past the small rubber sleeves covering the perforations, rupture the sleeve grout, and enter the soil. This device is suitable for injecting cement, clay, or chemical grout. The same holes and the same rubber-sleeved vents have been used in some instances for the injection of each of these grouts separately and in rotation into a soil. This permits economical treatment of soil containing large voids with an expensive chemical grout by first filling the large voids with less costly clay and cement grout.

(a) Clays and fine silts. Grouts in such materials can only displace the grains by penetrating planes of weakness to form lenses or by compacting the materials by forming grout bulbs. This type of grouting can be conducted using cements or cements proportioned with other fine solids.

(b) Medium and coarse silts and fine sands. Granular material through which water will move with relative ease will accept low viscosity chemical grouts to fill voids and form a more or less consolidated mass.

(c) Coarse sands and gravels. High viscosity chemical grouts and highly fluid cement slurries are usually found suitable for injection into such materials.

(5) EM 1110-2-3504 provides detailed information relative to the injectivity limits that may be expected of various types of chemical and portland cement grouts when they are injected into granular materials ranging from nonplastic silt to fine gravel. The limits are also shown in figure 5-1.

i. Specialized Applications. Many specialized applications of grouting are currently in use. A discussion of some of these applications is presented in Chapter 11. It is recommended that for specialized applications of grouting, or for any grouting using admixtures in the grout, laboratory tests be performed on the grout and field test programs be considered. Chemical tests of groundwater or mixing water in areas of suspected mineralized water should also be made, and the results should be used in the mix design.

4-6. Grouting Methods.

a. General Considerations. The best-known grouting methods are stage grouting, stop grouting, series grouting, circuit grouting, and tremie or gravity grouting. In each method the split spacing procedure is followed to determine final hole spacing. Holes for the initial or primary set are drilled at the maximum spacing (10 to 40 feet) and grouted, and the spacing of holes is reduced with each succeeding set until the criteria for completion of grouting are fulfilled. The holes for curtain grouting may be drilled on either a single-line or a multiple-line arrangement (para 4-5). Usually the grout curtain will be divided into horizontal reaches called sections. The length of the section is dependent on individual project characteristics, but may be based on not including more than three or four primary holes. Drilling of grout holes should not be allowed in the same section where grouting is being done, and sometimes not in the adjacent section. The purpose of this restriction is to limit the number of open ungrouted holes that could accidentally be grouted by interconnection and to prevent the disturbance of uncured grout by drilling fluids.

b. Stage Grouting.

(1) In the stage grouting method, progressively deeper zones are drilled and grouted in stages from the top of the grout hole. A stage of drilling is completed either when a predetermined depth of zone is reached or when a specified condition is encountered. A single zone may include more than one stage. Primary holes in a given area are drilled to the first stage of depth, grouting is done at low pressure, and grout within the hole is subsequently removed by jetting or other methods before it has sufficiently set to require redrilling. Similar stages of drilling and grouting are repeated as necessary to reach the bottom of the first zone.

(2) After all first-zone grouting of primary holes in the section or area has been completed and a minimum period of 24 hours has elapsed since the completion of grouting operations in any given hole, intermediate holes, located by the split spacing method, are drilled and grouted to the bottom of the first zone. Upon completion of all holes to the bottom of the first zone and after a 24-hour period, the primary holes are drilled to the next stage in the second zone and grouted at higher pressures. The process of drilling, washing, pressure testing, pressure washing, and grouting at progressively higher pressures is continued until the ground is satisfactorily tight to the required depth.

(3) The shallow zones of the grout curtain are initially grouted under low pressure; however, during grouting of deeper zones under the stage grouting method, the shallow zone is subjected to progressively higher pressures. Theoretically, the zone can withstand the higher pressures because the voids in the shallow zone should have been filled with grout during the low pressure grouting of the shallow zone. Normally, there is little or no intrusion of grout into this zone under the higher pressures used for deeper zones and no foundation lifting. There are exceptions, however, and the grout inspector must be aware of the possibility and must be prepared to stop grouting immediately to prevent heaving of the foundation.

(4) If any stage of a hole is found to be adequately tight as determined by pressure testing, grouting of that stage may be omitted and the hole left open for drilling in the next lower stage.

c. Stop Grouting.

(1) Stop grouting, sometimes called "up-staging," is a method whereby packers or expansion plugs block off preselected portions of the holes while those portions are being grouted. The holes are drilled to their full depth, are pressure tested, and are grouted in successive stops or zones from the bottom up. (An exception to the requirement of drilling the hole to final depth is made when lost circulation or artesian conditions are encountered. In either of these cases, the hole is grouted prior to drilling to final depth.) Packers or expansion plugs are set in the holes at the top of the interval to be grouted, blocking off the higher portions of the holes, and the interval is pressure-tested and grouted. The lowest zone is grouted first. The packers are then raised to the top of the next higher stop, and grouting is repeated. Grouting of holes of any one set (i.e., primary, secondary, etc.) should be completed for all zones in a particular section before drilling of split-spaced holes for the next set is commenced. Grouting pressures are ordinarily reduced with each higher stop because of less cover over the zone being grouted.

(2) Where grout communication from hole to hole is anticipated, a variation of the stop grouting method may be employed utilizing a multiple packer system. Experience has shown that holes grouted by transmission of grout from

an adjacent hole or holes are only partially grouted, and therefore incomplete. The multiple packer procedure consists initially of the simultaneous use of individual packers in adjacent holes during pressure testing. The procedure involves testing at least two holes in advance of the hole to be grouted to predetermine the zones of possible grout take ahead of the grouting schedule. (Figure 4-2 shows examples of multiple packer settings under various conditions of water take.) The packers are left in each hole just above the lowest take zone, and the hole is grouted under the maximum allowable pressure for the zone. This allows the header to be shifted from hole to hole and thus increases the effectiveness of the job. This procedure reduces the costly requirement of redrilling and regrouting holes that have been grouted by transmission (interconnection of holes). Knowledge of which adjacent holes accept water or grout is also helpful in determining the bottom hole depth for split-spaced holes.

d. Series Grouting. Series grouting is similar to stage grouting except that each successively deeper zone is grouted by means of a newly drilled hole to eliminate the need for washing grout out of the hole before drilling deeper. Holes at regular intervals are drilled to the depth of the first zone and individually grouted from the top of rock at low pressure. The split-spacing method of reducing the grout hole interval is followed until the uppermost zone refuses grout at the permissible pressure. After the first zone has been completed, another series of holes is drilled into the second zone and grouted from the top of rock at higher pressures, following the same procedure as outlined for the first zone. Additional series of holes may be drilled, depending upon the final depth of grouting required. Maximum pressure is applied to the deepest zone. The justification for using the higher pressures in the deeper zones with this method is based upon the assumption that a blanket or barrier, as provided by the previously grouted zones, prevents the escape of grout through, or the development of uplift in, the shallower zones. Sometimes this does not occur and grout is intruded into the shallow rock under high pressure. If this occurs, the foundation may be lifted and grouting must be terminated or packers used.

e. Circuit Grouting. Circuit grouting requires the use of a double line grouting system. The pump line is attached to a pipe that extends through an expansion plug or packer or special header to within 5 feet of the bottom of the hole. Grout venting from this pipe fills the hole, flows through a second opening in the expansion plug or header into the attached return line, and returns to the grout sump for recirculation. Thus, as soon as the pumping rate exceeds the rate at which grout is injected into the rock, the grout hole becomes part of the grout circulation system. Circuit grouting may be used to grout a hole drilled to full depth as a one-time operation, or it may be used as a modification of any of the other grouting methods described.

f. Gravity Grouting.

(1) Sometimes referred to as tremie grouting, gravity grouting is often

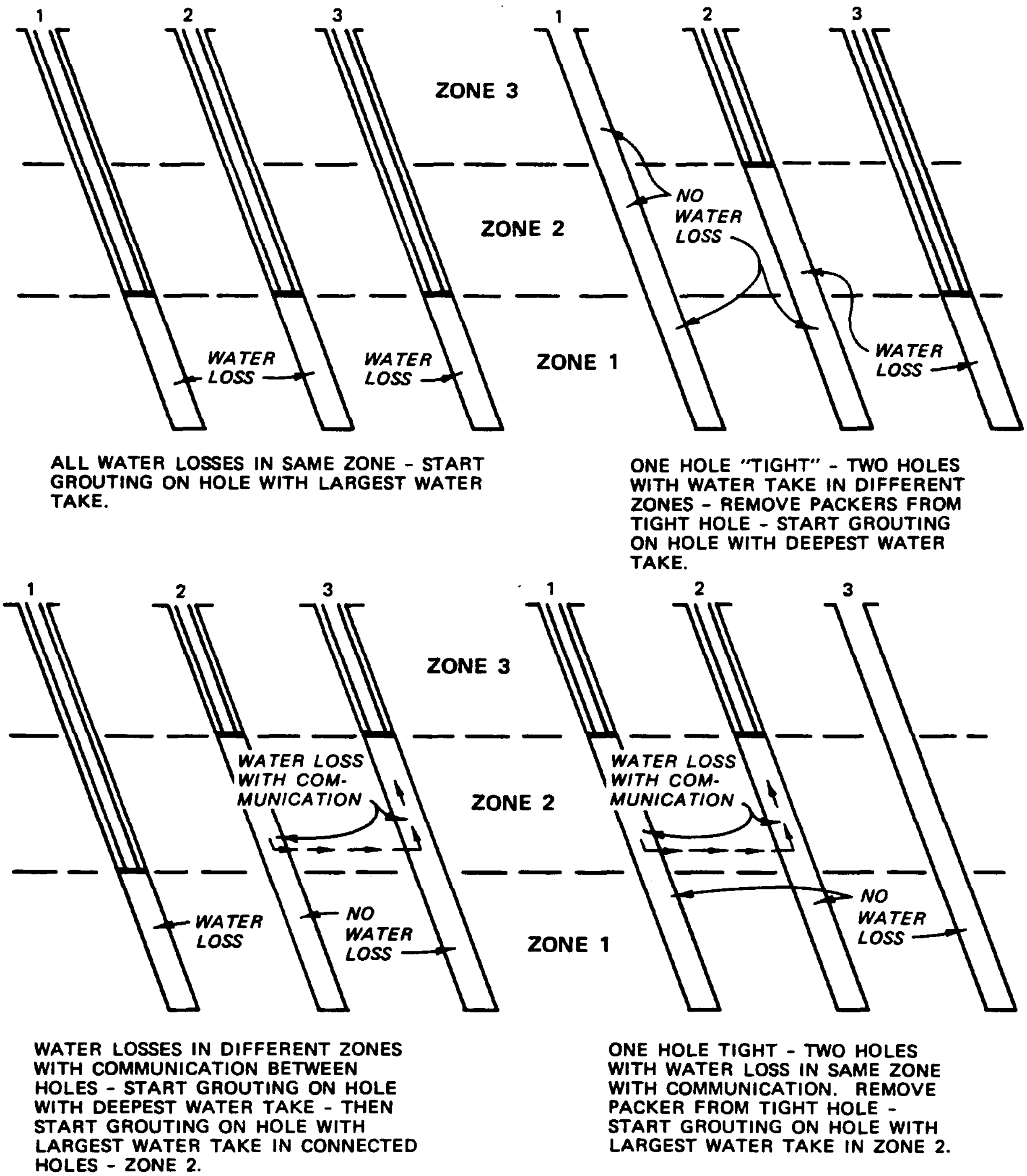

Figure 4-2. Examples of stop grouting with multiple packers

used in cases where large, open voids exist which will take grout freely. Examples of this condition are found in soluble formations, basalt flows, and mine cavities. The gravity technique consists of drilling the hole to total depth, lowering a grout pipe to near the bottom of the hole, and pumping in grout under near gravity pressure. When the pressure begins to build up, the grout pipe is slowly raised and the grouting is continued. The procedure is repeated until the hole is completely grouted. The grout pipe should be kept submerged in the grout at all times.

g. Critique of Grouting Methods.

(1) Stage grouting.

(a) Advantages. All stage grouting, regardless of depth of zone, is done from the top of the hole, usually through a short pipe or packer set in the top of the hole. This method eliminates the need for deep packer settings required for stop grouting. A smaller hole can sometimes be used for stage grouting than that for stop grouting since no packer is involved. Stage grouting has a flexibility that permits special attention to be given to almost any local condition encountered, provided the specifications are written to permit payment for the contractor's efforts. Drill cuttings from lower zones cannot clog groutable openings in higher zones. The grouting of all zones is done through a single hole, making drilling costs much less than those for series grouting, which requires a new hole for each cycle of drilling and grouting. Surface rock is subjected to increasing pressures and repeated application of grout from grouting of the deeper zones.

(b) Disadvantages. The principal disadvantage of stage grouting is the danger of lifting or heaving the surface rock when grouting without a heavy confining load. Heaving causes grout waste and may seriously damage the rock and/or any superjacent structure. Lifting occurs at comparatively low pressures when grout is actually injected into and displaces rock near the surface. Thinly bedded, horizontally stratified rocks and highly fractured rocks are easily lifted. A second major disadvantage of stage grouting, as compared to stop grouting, is higher cost. A drill must be set up over each grout hole at least once for each zone in the hole, and grout lines must be connected to the hole equally often. Both items add time and money costs to the job. Connections to grout holes are usually pay items, and more are required for stage grouting. Labor is expended and grout is wasted for each stage of grout hole that is cleaned before deepening. Premature cleanout may result in flowback of the grout injected into the rock, and this grout will also be wasted.

(2) Stop grouting.

(a) Advantages. This grouting method has several advantages: Imperfections disclosed by drilling operations may be isolated by means of the expansion plug and given special treatment. Only one drill setup per hole is required; pressure washing and testing may be concentrated in small segments of the holes by means of double expansion plugs, thereby improving the efficiency of these operations; cleaning or drilling out holes after grouting is unnecessary, less connections are required, and the method is more economical than the other methods.

(b) Disadvantages. Some disadvantages of stop grouting are: grout sometimes bypasses the grout stops, or expansion plugs, through vertical or near vertical fractures or joints; a tight seal is difficult to obtain with expansion plugs in fractured or broken rock, and in cavernous or solution honeycombed rock; leaks into nearby holes may cause difficulties and may plug fractures and seams and other imperfections in those holes above the zone being grouted; and sizes of holes that can be used for grouting are limited to the sizes of packers or expansion plugs obtainable. Packers are frequently lost due to their becoming grouted into the hole.

(3) Series grouting.

(a) Advantages. The advantages stated for stage grouting (except the last listed) also apply to series grouting. Other advantages of series grouting are that all grouting is done from a new hole in freshly exposed rock, providing maximum exposure of groutable voids, and grout injected into the rock is not lost by poorly timed cleanouts as in stage grouting.

(b) Disadvantages. The major disadvantages of stage grouting, which are the danger of heaving and an increased expenditure of time and money, apply to series grouting also. The increased amount of drilling makes series grouting the most expensive of the methods described. There is a much greater danger of heaving the surface rock with series grouting than in stage grouting.

(4) Circuit grouting.

(a) Advantages. Grout is kept alive in the entire hole until grouting is complete. Thus, small openings occurring below large ones can be grouted after the large openings are filled. Caving holes can be grouted by jetting the grout pipes through the caving zones. Holes can be flushed more thoroughly during the grouting operation in circuit grouting than by any other method. Caving or sloughing materials are removed from the hole by the rising column of grout and later removed from the system by a screen placed between the return line and sump.

(b) Disadvantages. If the packer is set near the top of the hole, the entire hole must be grouted at a sufficiently low pressure to prevent lifting of surface rock. If the packer is set several feet below the surface, the upper part of the rock is ungrouted. A larger hole must be provided to permit installation of the assembly. Excessive time is required to assemble and disassemble grout pipe in the hole. In addition, the cost is higher than for stage or stop grouting.

(5) Combining methods. No large grouting job is likely to be completed using only one grouting method in the strictest sense of the definitions. For example, the drill water may be lost during the drilling of a hole for stop grouting, and drilling must be stopped immediately and the hole grouted. In such cases it can be said that stop grouting is done by stages. In stage grouting if the upper rock is so fractured that it cannot be sealed well enough to withstand the higher pressures desired for the lower zones, it may be necessary to grout the lower zones through a packer set below the fractured rock. This is also a combinaton of the stage and stop grouting methods. In some cases circuit grouting may be used in fractured zones. A badly fractured upper zone extended over a considerable area may require treatment by a grid of shallow holes grouted by the series or stage methods. The grid forms a grouted rock blanket before stop, stage, or series grouting is continued in the lower zones of the area. Specifications should be flexible enough to permit the use of the method or methods best suited to whatever situation is encountered and should provide a means of compensating the contractor for the work performed.

(6) Selection of method. Stage grouting and stop grouting are the two most common methods of grouting. Service records show that effective results can be obtained by either method. If grouting is delaying another construction operation and time is an important factor, stop grouting should be given serious consideration. If higher pressures are needed in lower zones of the grout hole than near the top, stop grouting is the best suited method. Examples of the latter are reservoir rims, dam abutments, mine shafts or other similar deep excavations, and underground structures grouted from the surface. Portions of grout holes must occasionally be drilled through rock above the horizons requiring treatment. Since grouting the upper rock is unnecessary, stop grouting is well adapted to this situation. If sufficient rock overlies the grouting horizon, the entire hole may be grouted with one stop and with only low or gravity pressure at the collar of the hole. If the surface rock in the grouting area is thinly bedded and has a nearly horizontal attitude, stop grouting is the best method to avoid lifting. A stage of grouting is usually required if the drill water is lost before the hole reaches final depth. Stage grouting should be used to prevent natural muds formed by drill cuttings from shales or similar rocks from filling or obstructing groutable openings at higher horizons. Consolidation of the upper rock may be desirable or necessary before any grouting at depth proceeds, and will necessitate the stage or series grouting method. If grouting the foundation of an existing structure is desired at pressures comparable to the load imposed by the structure, great care must be exercised to avoid heaving and tilting the structure. The danger of heaving is less if the rock is massive or medium bedded, the joints are at high angles, or the strata are steeply dipping.

4-7. Foundation Drainage.

a. Galleries are generally provided in concrete dams for drilling, grouting, and drainage. Where possible, the minimum size of the gallery should be 8 by 8 feet.

b. In addition to grouting, drainage may be required to control seepage and pressures in foundations or abutments. Foundation drainage features, filters, and other measures act together, or in combination with the grout curtain (if present), to control seepage, reduce pressures, and prevent piping. Foundation drainage features include drilled drains, relief wells, drainage adits, drainage galleries, and pervious drains or filters.

c. Galleries have not been constructed in embankment dams built by the Corps of Engineers but may be considered for future projects.

d. Drainage is one of the most effective means of seepage control. Drains should not be drilled until after grouting has been completed. When grouting is necessary near existing drainage features, caution is necessary to avoid grouting the drains or wells. Effectiveness of the drainage features should be checked after the grouting program, and the drains or wells should be cleaned and/or rehabilitated and new drains or wells provided as necessary.

e. Foundation drains in galleries are frequently inclined downstream to increase the distance between the drains and the grout holes. Drain holes should be a minimum of 3 inches in diameter and may or may not be lined with slotted polyvinyl chloride or metal casing, depending on the geologic conditions and groundwater. Gravel or sand should never be used to fill the hole.

f. Drains in tunnels and abutments may be horizontal or inclined at any angle. If drains are horizontal or inclined upward in shale or other sensitive materials, they should be provided with traps at the collar to prevent air circulation in the hole and should be cased if necessary.

g. Drains should be designed so that they are accessible and can be periodically inspected and cleaned.